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Impacts of Climate Change on Rice Yield

Case: Nam Xong River Basin

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Most of the farmers in Lao PDR cultivate rice as the source of living. Most of the area used for rice cultivation is rainfed rice. The agriculture of a vast population in Nam Xong River Basin is dependent on monsoons where rice is grown between May and November. The most important parameters to determine the yield variation in the region is the climate and soil contrast.

Nam Xong River Basin is located in the Vientiane province. It is divided into mountainous upper Nam Xong, valleys in the middle and flat plains in lower plains. Rainfed rice cultivation is largely located in the valleys (Vangvieng) while irrigated agriculture can be found in lower Nam Xong. The variation of rice yields in the Nam Xong water shed is mostly due to the variation in rainfall.

IWRM model is hydrological model based on grid representation of the modelled catchment. The precipitation and temperature were taken as input in IWRM model. Soil and water parameters were calibrated in the model to get output yield closer to observed yield. After calibration, climate change scenarios were taken as input for yield projection.

Vangvieng possesses high rice yield among all other agricultural study areas. It receives high and sufficient rainfall which has a beneficial effect on rice cultivation whereas lower Nam Xong receives less rainfall. This paper examines the rainfed rice cultivation practice in the Nam Xong basin. It focuses on the climate change and its significant impact on rice yields. Particularly, the climate induced precipitation change is discussed in this paper.

Based on the findings, it was discovered that there is a moderate impact of climate change on rice yields. Under climate change scenarios, the rainfall received by Vangvieng is excessive which is the main cause for reducing yield. The impact caused by the precipitation change is approximately 1.5% loss in rice yields. Social and economic factors are not considered. Due to the lack of reliable irrigation data, the research is only limited to the rainfed rice cultivation.

Keywords	Agriculture, Rainfed rice, Rice yield, Climate change

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List of Abbreviations

NXRB	Nam Xong River Basin
MRC	Mekong River Commission
IWRM	Integrated Water Resource Management
HBV	Hydrologiska Byråns Vattenbalansavdelning
DEM	Digital Elevation Model
GIS	Geographic Information System
EIA	Environmental Impact Assessment
Lao PDR	Lao People's Democratic Republic
IPCC	Intergovernmental Panel on Climate Change
SRES	Special Report on Emission Scenarios
AR5	Fifth Assessment Report
FAO	Food and Agriculture Organization
IRRI	International Rice Research Institute
USDA	United States Department of Agriculture
GHG	Greenhouse gas
CO_2	Carbon dioxide
CH_4	Methane
N_2O	Nitrous oxide
T/ha	Tonnes per hectare
GCMs	General Circulation Models
ADB	Asian Development Bank
NREI	Natural Resources and Environment Institute
NASA	The National Aeronautics and Space Administration

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1 Introduction

In Asia and the Pacific regions, developing countries are likely to face reductions in agricultural production potential due to global climate change (ADB, 2009). With rapid development in technology, transport and industries, increase in human activities in agriculture and deforestation, there has been a rapid increase in the emissions of greenhouse gases causing climate change. According to IPCC, Fifth Assessment Report (AR5), “Warming of climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen”. The averaged combined land and ocean surface temperature throughout the planet indicates a linear trend show a warming of 0.85 [0.65 to 1.06]^{o}C over the period 1880 to 2012 (IPCC, 2014).

Agriculture is highly dependent on climate patterns and variations such as solar radiation, temperature, and precipitation. Changes in temperature, amount of CO_2, the intensity of extreme weather have a mixed impact on crop yields, for example, increase in temperature can be beneficial for some crops and detrimental to others. Climate change can have indirect impact on agriculture by affecting nutrient levels, soil moisture, water availability, etc. (Perry, 2009). Agriculture is expected to be affected by climate change in South East Asia in several ways. Due to changes in precipitation and runoff, and subsequently, water quality and supply, crop yield can be affected. Yet the region already faces water stresses due to dense population in the area, and future effects of climate change on regional rainfall will therefore have both direct and indirect effects on agriculture (IPCC, 2007).

Rice is a popular food throughout Asia. It is the main crop cultivated throughout the Asia. The research indicates that 90% of the world’s production and consumption of rice occurs in this region (Jha, et al., 2010). The accepted indicator In the Mekong River region, shows that climate change is happening in the last 10-30 years as possible changes in rainfall and temperature have been detected which can reduce agriculture output and yields particularly for rice due to higher temperature during the crop season, higher temperatures during the flowering of rice, droughts and floods (Shivakoti, et al., 2014).

2 Theoretical Background

To evaluate the rice yield from the model, it is essential to understand the rice cultivation tradition, climate and geographical factors affecting the growth of the plant. Some of the key parameters related to rice cultivation and growth are discussed below.

2.1 Rice Cultivation

Rice is the second most harvested crop globally after wheat in terms of the harvest area (Garbach, et al., 2014). It is consumed as the major source of calories by the one-third of the world’s population. South and Southeast Asia have largest rice-growing area, but most of the rice is grown in lowland and is primarily rainfed cultivation (Garbach, et al., 2014). More than 10 million hectares of Mekong River Basin is flooded with rice cultivation, where 60% of the rice field is rainfed which is higher irrigated systems (Shivakoti, et al., 2014).

Rice is a tropical and subtropical crop and is the best suitable in temperate regions where the highest grain yields are obtained. It is suitable and mostly grown in flat, lowland river basins and delta areas in Asia, which is the also primary reason for the remarkable population growth in the broad wetlands in Asia (De Datta, 1981).

Rainfed rice farming is the traditional type of a farming system practised in tropical climate regions, which is basically a self-nourishing system i.e. depends on climate patterns and soil. For the growth and development of rice, rainfall is the only source of water in uplands whereas, rainfall as well as diversion from rivers, streams, etc. are the source in lowlands.

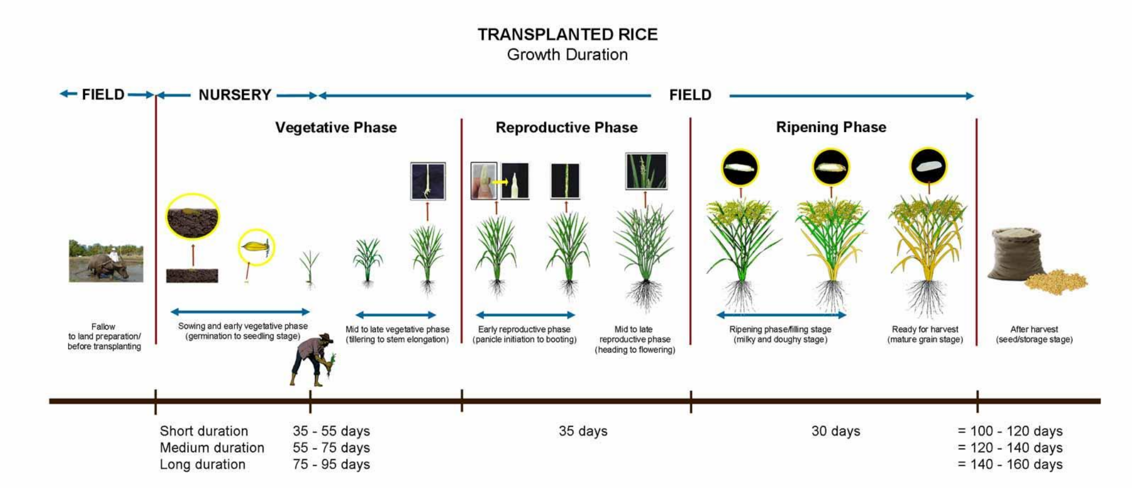

Figure 1. Growth duration for transplanted rice (IRRI, unknown)

For the wet season, rice is usually cultivated from May to June, and the medium duration until harvest of the crop is 120-140 days. The growth duration of rainfed rice is categorized into vegetative, reproductive and ripening phase.

Generally high yields are obtained in temperate regions due to lower temperature during night time especially at the reproductive phase of growth. However, yields can be different in different regions due to various factors such as land preparation, seed quality, water, pest and nutrient management and other post production factors, such as harvesting and drying. One of the main factors for yield variation in rainfed rice cultivation is due to farmers socio-economic status, education level, agriculture management skills, decision making, and infrastructure used for farming (FAO, 2000).

2.2 Climate Change

The climate is the global average of temperature, humidity and rainfall patterns over long term periods such as seasons, years or decades. Climate change is a broad range of global phenomena which is primarily and predominantly created by burning fossil fuels, which add heat-trapping gases to the Earth's atmosphere. These phenomena include the increased temperature trends described by global warming, but also relates to sea level rise, ice mass loss, shifts in plant blooming and extreme weather events (NASA, 2016). According to the Intergovernmental Panel on Climate change (IPCC) Fifth Assessment Report (AR5), impact of human activities in climate system is clear. Recently, anthropogenic emissions of greenhouse gases are the highest in history. The consequence of emissions on atmosphere is causing global warming and such climate changes have negative impacts on human and natural systems.

The anthropogenic degradation of the environment and naturally occurring disasters on global environment have been the key factors to the climate change. Energy consumption and land-use change are the two most important drivers of anthropogenic climate change. Since the pre-industrial era greenhouse gas (GHG) emissions have caused large increase in the atmospheric concentrations of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O).

Activities including deforestation and the combustion of fossil fuels have released large quantities of GHG into our atmosphere. Large area of forest has been replaced by agriculture which contributes 10 to 12 percent of annual anthropogenic GHG emissions. Half of these emissions from agriculture are produced as a by-product of the rice cultivation, digestion process of corn-fed cattle and management of livestock waste (Downie, et al., 2009).

According to IPCC, since 1850, the average global temperatures have risen nearly 1^{o}C. Eleven of the past 12 years were recorded the hottest ever globally. By the end of 21st century, the IPCC AR5 reports that temperature will rise 1.1 to 6.4^{o}C with the range largely dependent on GHG emissions in future. Food security is projected to threaten by climate change due to reduction in agricultural production. Due to the projected climate change by the mid-21st century, for rice, climate change without adaptation and mitigation is projected to affect agricultural production negatively for local temperate increases of 2^{o}C or more above late 20th century levels (IPCC, 2014).

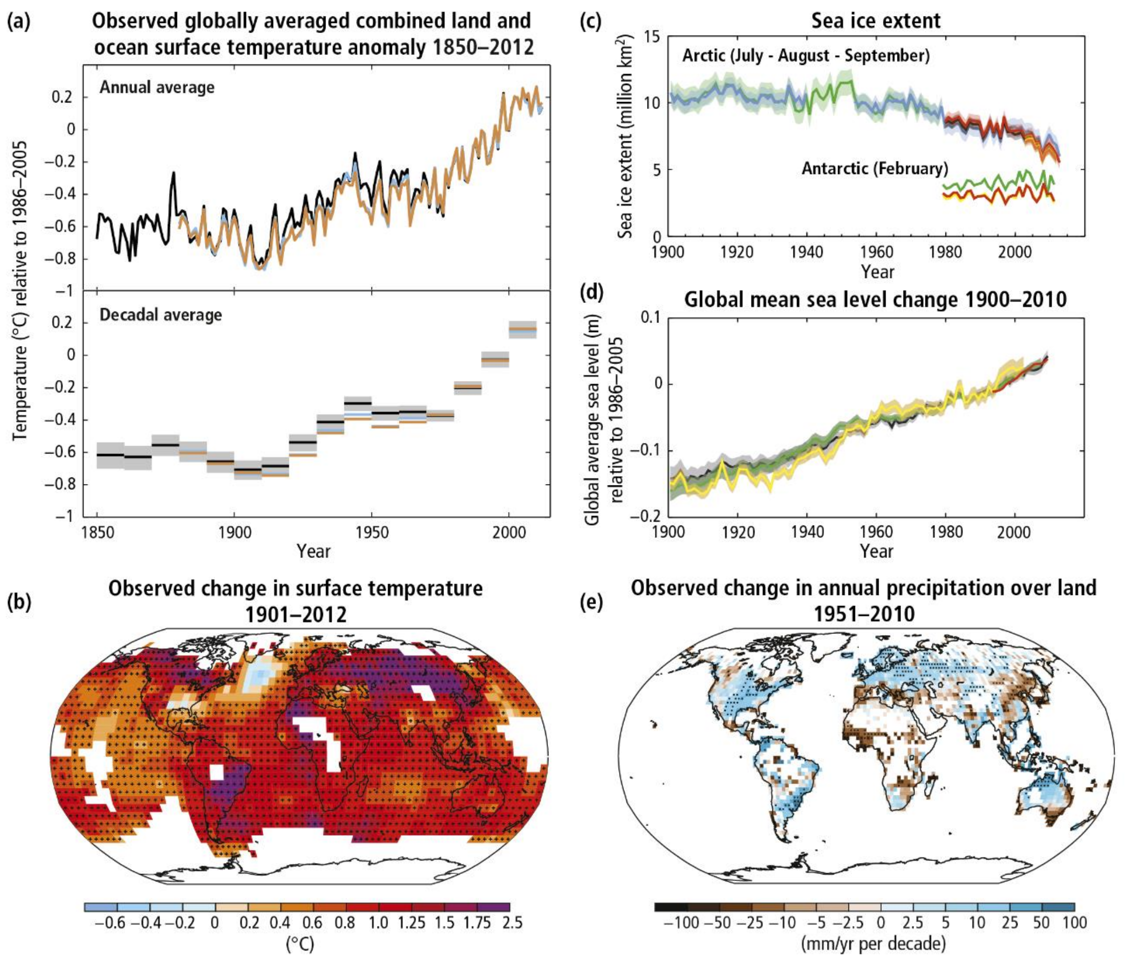

Figure 2. a) Observed average land and ocean surface temperature (1850-2012) b) Observed change in surface temperature (1901-2012) c) Sea ice extent d) Global mean level change (1900-2010) e) Observed annual precipitation change over land (1951-2010) (IPCC, 2014)

According to the IPCC, Fifth Assessment Report (AR5), last three decade has been the warmest period of the last 800 years, ocean warming is dominant in energy accumulation in the climate system and global sea level has risen by 0.19 [0.17 to 0.21] m as shown in Figure 2.

2.2.1 Emission Scenarios (A2, B1)

The IPCC have developed emission scenarios and is a tool or images of future, which can be used in a climate change analysis, climate modelling and assessment of impacts, adaptation, and mitigation. These emission scenarios are determined by demographic development, socio-economic development, and technological changes (IPCC, 2000).

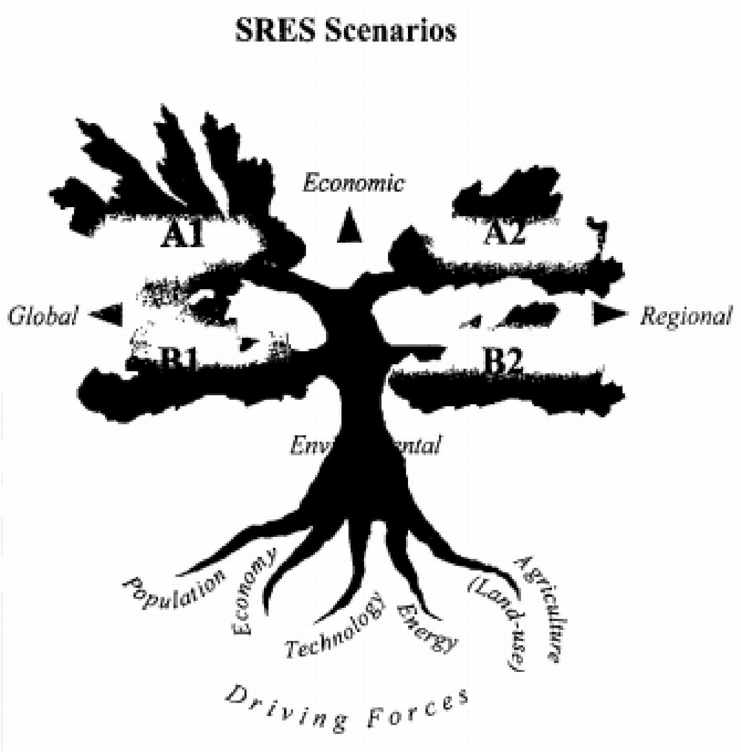

Figure 3. Schematic illustration of SRES scenarios (IPCC, 2000)

The A2 scenario developed by IPCC describes a very diverse world which focal point is regional level and emphasis on preservation of local identities, high population growth due to very slow fertility pattern, regionally oriented economic development, per capita economic growth, technological change which are more shattered and slower than in any other storyline (IPCC, 2000).

The B1 scenario describes the world which has a low population growth with swift changes in service and information economic structure and reduction in clean and resource-efficient technologies. It focuses on global solutions to socio-economic and environmental sustainability without an additional climate strategy (IPCC, 2000).

2.2.2 Climate Change impact on Agriculture and Rice cultivation

Climate patterns and variations have a high impact on Agriculture. Climate change is projected to threaten global food security. Due to warmer temperatures, large varieties of crops grow more quickly, but warmer temperatures can also reduce yields. Crops trend to grow faster in warmer conditions. For some crops, such as grains, faster growth can reduce the amount of time that seeds have to grow and mature which can reduce yields. (IPCC, 2014).

Agriculture is the main source of livelihood for most people in Nam Xong river basin. In the past few decades, the research on climate change indicates that the production of rice, maize and wheat has declined in different parts of Asia. The declination in production is caused by water stress mainly from increasing temperature, increasing frequency of El Nino and limited rainy days. But the increase in summer rainfall may benefit crop production, crop stress from rising temperatures can offset such benefits, particularly the yield of rice. Changes in the amounts of CO_2, frequency and intensity of extreme weather conditions such as floods and droughts, are expected to make local crop production even more difficult (Rojas, et al., 2014).

2.3 Role of Climate and Soil Parameters for Rice Growth

The yield potential of the crop mainly depends on the climate. The most important factors that influence growth, development and yield of crops are temperature, precipitation and solar radiation.

2.3.1 Temperature

Rice is a cold-sensitive plant that originates from tropical or subtropical zones. The growth of rice is impressed by limited period that favours its growth in temperate regions. An optimum temperature is required for maximum dry accumulation. All crops have maximum, optimum and minimum temperature limits. The response of the rice plant to daily mean temperatures at different growth stages are provided in Table 1.

Table 1. The response of the rice plant to varying daily mean temperature at different growth stages (Yoshida, 1981).

Growth Stages	Critical temperature (°C)		
	Low	High	Optimum
Germination	10	45	20-35
Seedling establishment	12-13	35	25-30
Rooting	16	35	25-28
Leaf elongation	7-12	45	31
Tillering	9-16	33	25-31
Primordia initiation	15	-	22-23
Panicle differentiation	15-20	38	-
Anthesis	22	35	30-33
Ripening	12-18	30	20-25

A high temperature for rice beyond the optimum range affects mineral nutrition, pollen development resulting in low yields. The nutrient uptake is also affected by both soil and air temperature in rice. High temperature at 38°C can reduce the plant height, and make smaller roots. The maximum temperature that rice plant can tolerate is 45°C during daytime and minimum temperature is 7°C during night time (Basnayake, et al., 2006).

2.3.2 Precipitation

Rainfall is one of the key climate parameters for rice cultivation because large volumes of water are needed to produce rice. Rainless days have direct impact on rice yield as two weeks without rain in lowland areas and about a week in upland areas can significantly reduce yields. Extreme drought for years can reduce the average yield from 17 to 40% leading to production losses and food scarcity. The intensity and frequency of droughts are predicted to increase in rainfed land and droughts could extend further into water short irrigated areas. More than 23 million hectares of rainfed rice production areas are affected by a water scarcity in South and Southeast Asia (IRRI, 2016).

In rainfed cultivation, crops are planted according to the season and rice is planted during the wet season. The production yield has direct dependency on rainfall received during the crop season. Heavy rains with short frequencies will result in floods and decrease yield whereas excess rainfall can cause an alteration of chemical and biophysical processes. Heavy rainfall can cause problems in drainage of roots which can block free movement of oxygen and also can result in formation of toxic compounds harmful for roots. Inadequate rainfall causes water stress which reduces the size of inflorescence, and finally affects fertilization, gain filling and reduce final yield (Rana & Randhawa, 2014).

Both low and excessive rainfalls can have a negative impact on rice yield. Excessive rainfall can interfere with different farming activities such as seedbed preparation, harvesting, processing and drying of seed. It can also increase the chance of spreading diseases in the plants. The fertilization and grain formation of rice plant is also affected due to the continuous rainfall for longer period of time (Basnayake, et al., 2006).

2.3.3 Solar radiation

Solar radiation is an important factor needed for the growth and development of rice plant. Solar energy provides light required for seed germination of seed, expansion and growth of leaf, stem and shoot. Sun also provides thermal energy necessary for the physiological development of the plant.

The average daily solar radiation in the tropical agriculture is one and a half times lower than temperate rice-growing regions during wet season. But the farmers practicing rainfed rice cultivation in the tropical region must grow crops when there is low intensity of sunlight due to dependency on rainfall. Due to higher intensity of solar radiation during dry season, the grain yield of can be higher than in the wet season (De Datta, 1981).

Solar radiation is low in the wet season under tropical conditions because, the radiation is trapped or intercepted by clouds. But low radiation does not have a significant effect during the early vegetative stage of rice plant however, it can have an effect during the reproductive phase (De Datta, 1981).

2.3.4 Soil Stress

Soil stress relates to the characteristics of the soil, such as water holding capacity, drainage, depth, texture, organic matter and fertility. Higher the soil stress can decrease the rice yield. Various forces acting on the soil water decrease the soil potential energy and makes it less available for root extraction. In wet soils, the potential energy of water is relatively high. This allows water to move freely in wet soils and water can be easily extracted by plant roots. The potential energy of water in the dry soil is very low compared to wet soil, and is strongly bound by capillary and absorptive forces to the soil matrix, and is can be difficult for a crop to absorb water. Excessive soil water stress can result in pollination failure, and trigger early canopy senescence (Raes, et al., 2012).

2.3.5 Potential Evapotranspiration and length of growing period

Potential evapotranspiration (petcorr in IWRM) is a measure of the ability of the atmosphere to remove water from soil and plant surface through evapotranspiration (evaporation and transpiration) without the limitation of water supply. It is very important parameter for the growth of rice plant. If petcorr exceeds rainfall, then irrigation is required for optimum growth of rice plant. The usual petcorr level used by FAO for upland crops is 50% but for Lao PDR, it is estimated to be 75% (Basnayake, et al., 2006).

Day length also plays a vital role in rice growth. The growth of rice is favoured by shorter days. Lao PDR have relatively smaller day length variation than other countries and due to this, the wet season is very productive for flowering of rice. During short days, the flowering and reproduction of plant are developed quickly. The traditional rice varieties of Lao PDR are usually highly photoperiod sensitive and rice plant flowers from September to mid-October (Basnayake, et al., 2006).

2.4 IWRM model

Integrated Water Resources Management (IWRM) is a distributed physically based/conceptual hydrological model based on grid representation of the modelled catchment. This model which is called Vmod is distributed in the EIA hydrological modelling software. It includes lumped Hydrologiska Byråns Vattenbalansavdelning (HBV) for basic and fast hydrological modeling. In the model, the simulation of hydrological processes in the catchment are based on simplified physically based formulations (Koponen, et al., 2010).

The model is based on rectangular grid, where each grid cell has its own sets parameters such as ground slope, vegetation and soil type and is computed individually as shown in Figure 4 below. Hydrological processes such as precipitation, snow hydrology, infiltration, evapotranspiration, seasonal vegetation development, soil water content, groundwater height, and flow into streams are simulated in each grid cells (Koponen, et al., 2010).

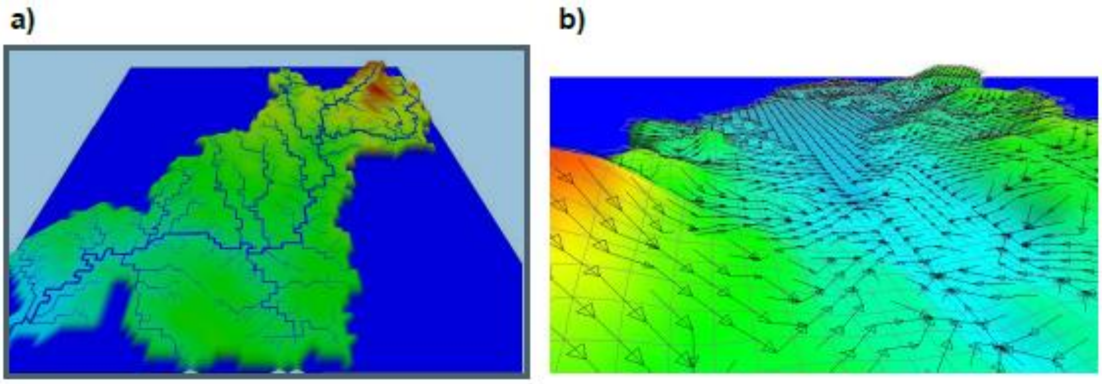

Figure 4. Visualization of a IWRM model grid, displaying a) land elevation with colors and stream flow network and b) surface flow routing directions (Koponen, et al., 2010).

The IWRM model have wide range of applications such as general hydrological modelling, time series analysis, land use planning, flood management, water quality management, irrigation, climate change assessment and adaptation, etc. FAO56 crop model has been integrated in the model system for the crop yield optimization. In grid cells containing ground the calculation is divided vertically from top down to vegetation layer, ground surface layer and two soil layer as shown in Figure 5 below.

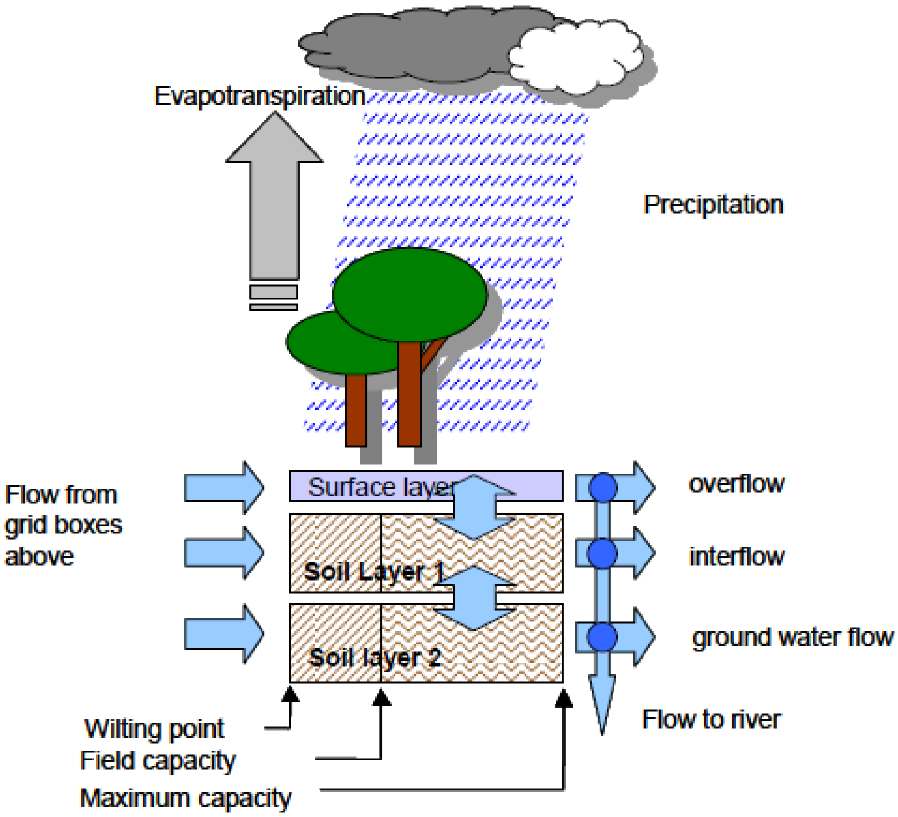

Figure 5. Components of grid cell water balance in IWRM model

In the calculation of grid cell, different processes are taken into account such as interpolation and correction of meteorological data (Temperature and Precipitation), infiltration of water in the soil, crop water demand using FAO56 method of calculating evapotranspiration for different crops, water movement between soil layers or between grid cells or grid cell to river, etc. (Koponen, et al., 2010).

3 Description of study area

The Nam Xong river basin is located in the central part of northern Lao PDR, and is 83 km north of Vientiane and 14 km south of Kasy. The total area covered by basin is 180,434 ha and is the third largest sub-basin out of the 18 sub-basins that make up the Nam Ngum Water shed. Vangvieng is the largest city and is located in the center of the Nam Xong basin. Rice farming accounts for total 2.89% of total area of NXRB and is the major crop in the basin. Vientiane province makes up 97.3% of the area while remaining area is covered by Luang Prabang province. (DWR, 2009).

3.1 Geography, Climate and Population

The Nam Xong basin borders the Nam Lik sub-basin to the west and south, the Nam Ting to the North, the Nam Meuy and Nam Pat sub-basin are to the east. It is divided both geologically and by the Nam Xong Diversion Dam. Above the dam, there are three major tributaries, which made up to three main valleys.

The NXRB has a tropical climate with a single monsoon season between May and September, which can extend into October. During monsoon season, the basin receives 96% of its annual rainfall (Miaillier, 2007). Rainfall reaches to maximum of 766mm in July. The annual precipitation varies from 17 to 766mm in which June to August is over 700mm. Temperatures are relatively high with an average temperature between 24 and 30^{o}C throughout the year. The temperature can rise up to 40^{o}C in March and April whereas in December and January, the temperature can drop to below 14^{o}C (DWR, 2009).

Table 2. Vangvieng Climate (DWR, 2009)

Month	Ave. Sunlight (hr)	Temp				Discomfort for heat humidity	Relative humidity	Ave. Precip-itation (mm)	Wet day (+0.25 mm)
		Aver		Record					
		Min	Max	Min	Max				
Jan	8	14	28	4	35	medium	77	28	1
Feb	8	17	30	8	37	high	75	51.7	2
March	7	19	33	12	40	extreme	71	80.6	4
April	8	23	34	17	39	extreme	74	137.7	7
May	7	23	32	21	39	extreme	82	435	17
June	5	24	32	21	36	extreme	85	727.7	17
July	5	24	31	21	34	extreme	87	765.5	18
Aug	5	24	31	21	37	extreme	86	756.4	18
Sep	8	24	31	21	35	extreme	86	431.1	16
Oct	8	21	31	13	34	extreme	82	269.6	7
Nov	8	18	29	11	34	high	79	81.4	1
Dec	8	16	28	5	33	medium	78	16.5	1

Table 2 shows the climate of Vangvieng District. According to the table, due to high humidity and temperature in wet season, can cause extreme discomfort.

The elevation varies from 150 m in the lowlands valley to the maximum of 1500 m in the north. The southern area of the basin is plain while the northern part is mountainous. The northern region of the basin has extreme topography with slopes exceeding more than 30% in some areas. The north has narrow valley floors and is limited to rice crops for agriculture and the southern regions are rolling hills which support agriculture, rice production and plantations (DWR, 2009). The elevation map is shown in Figure 6.

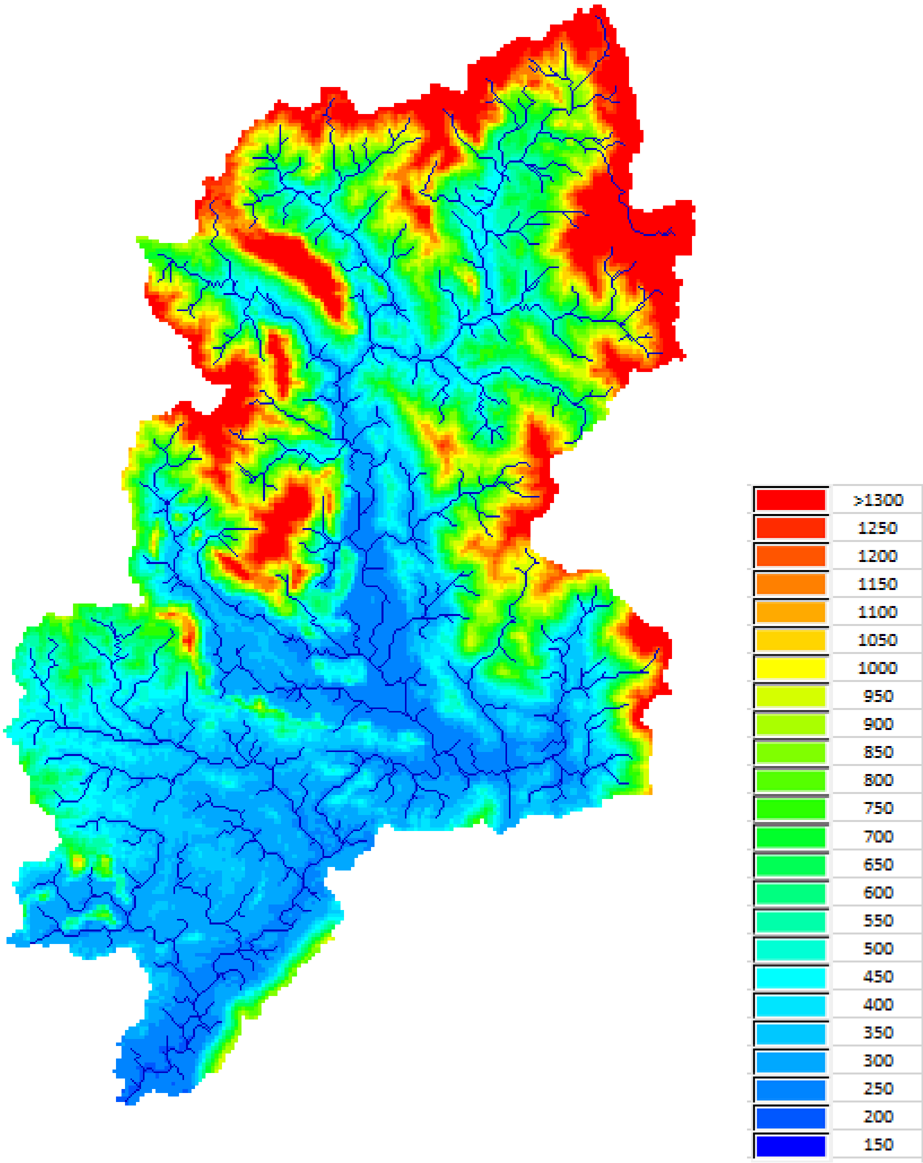

Figure 6. Map of elevation (meters) and river network calculated with RiverLife GIS based on the DEM in the NXRB

The entire NXRB is located within Vientiane Province which represents 100% of population. Most of population in basin is concentrated in Vangvieng district and remaining in Kasy, Hinhurp and Feuang district as can be seen in Figure 4 below. The population in NXRB recorded in 2008 was 54,493 (DWR, 2009).

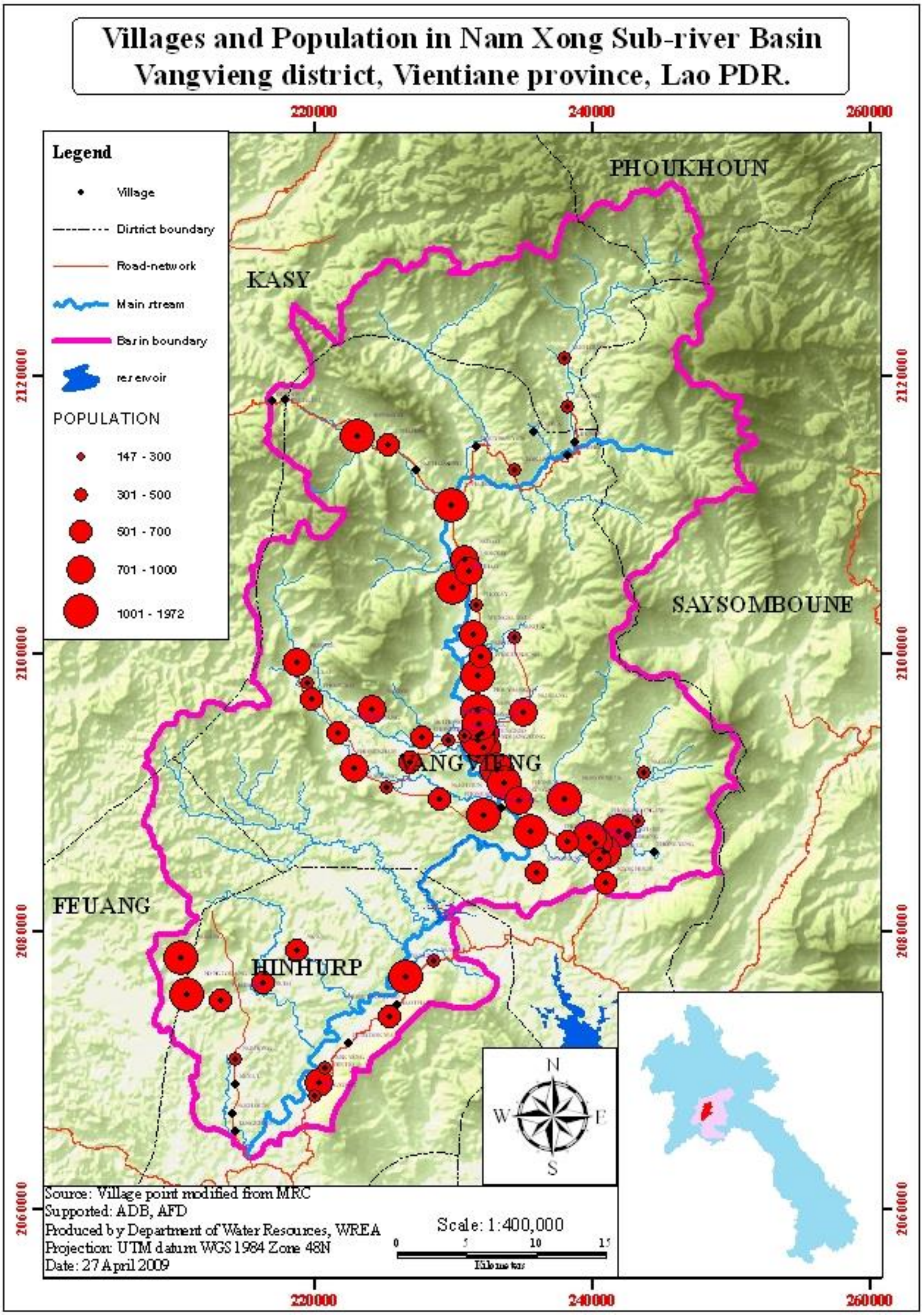

Figure 7. Villages and population in Nam Xong Sub-basin (DWR, 2009)

Above figure indicates that, majority of the population are distributed along the water-ways.

3.2 Soil and Land use

Soil in the basin is dominantly acrisols and is found widely throughout the basin. The remaining are histosols, ferrasols and lithosols which make up to 6% of the area. Acrisol is one the 30 soil group classification system of FAO, and has low level of nutrients, excess aluminium, and high erodibility which can lead to less agricultural productivity.

Table 3. Soil type classifications and their abundance in Nam Xong River Basin. Data acquired from the model.

Soil type	% of area
Water	0
Acrisols	94.67
Histosols	0.89
Argic	0
Ferrasols	0.37
Alluvial	0
Lithosols	4.07
Cracking	0

The area is divided into agriculture, shrub grassland, deciduous forest and urban areas. Most of the area of the basin is covered by Deciduous and Shrub grassland. Only 0.02% of the land use accounts for a urban area. Shrub grasslands cover the highest area in lowland whereas deciduous forests cover the highest area in mountains.

The land use area for agriculture is divided into rainfed and irrigated areas. Approximately 4.5% of land in lowland valleys is used for rainfed agriculture but only 0.1% in the mountains. Similarly, only 1.8% of the land is used for irrigated agriculture in lowlands while 0.1% used in mountains or upland.

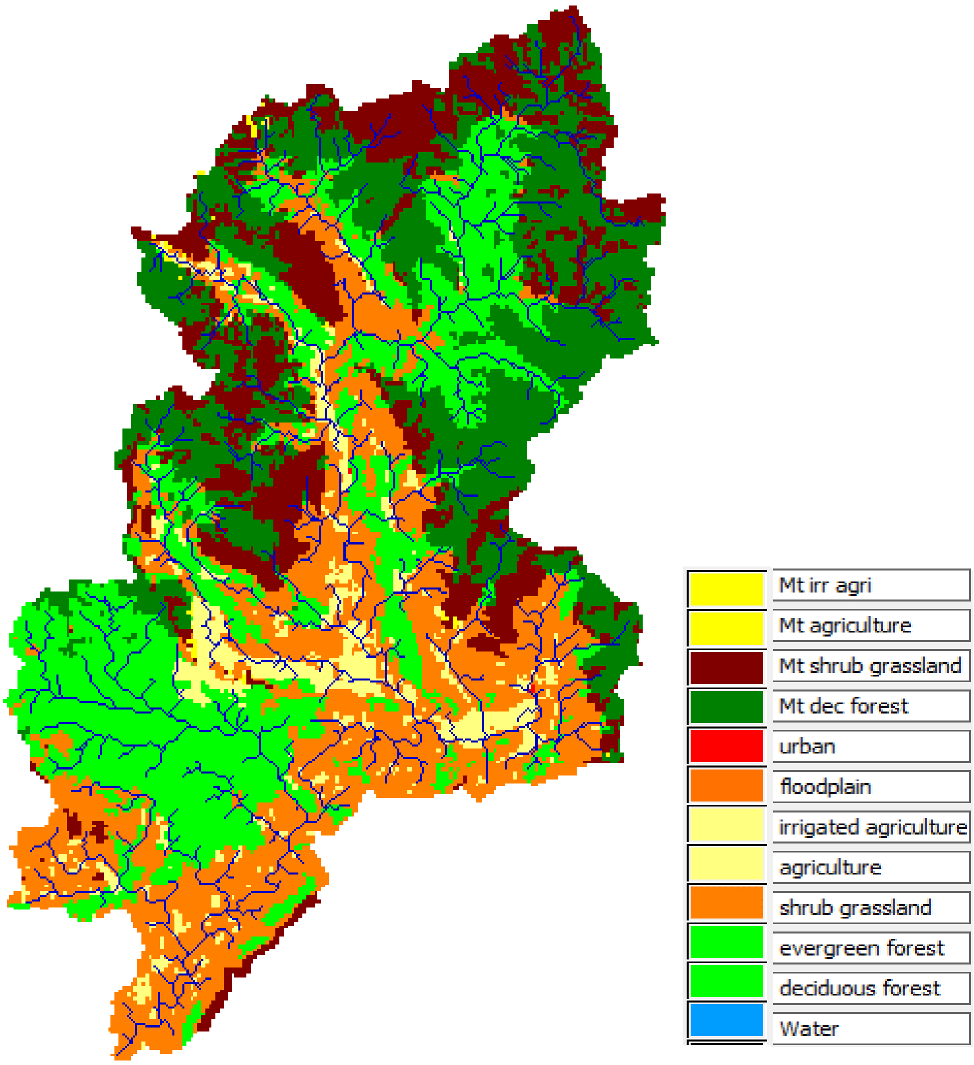

Figure 8. Land use area in Nam Xong River Basin. Data acquired from the model

3.3 Agriculture

Agriculture is the way of living in NXRB. It is not only the source of food but also income. Most of the farmers are engaged in rice and vegetable cultivation. Agriculture accounts for 6% in the lowland valley but only 0.2% in the mountains. Rice is the main crop in the basin. Rice is followed by cash crops such as corn, watermelon, squash, pumpkin, chilli, etc. Fruit trees are also grown in the basin which is larger than vegetables and the popular fruit trees are small orange, lime, coconut, jack fruit, mango, etc. (DWR, 2009). The agricultural rotation in NXRB is provided in Table 4.

Table 4. Agriculture rotation in Nam Xong basin (Miaillier, 2007).

Land Type	Rotations	Dry		Wet								Dry	
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Slash and Burn	1						Rice						
	2						Cassava						
	3						Maize						
Paddy fields	1								Rice				
	2										Rice		
	3	Groudnut							Rice				
	4	Vegetables							Rice				
Upland fields	1							Groundnut					
	2	Vegetables											
	3						Fruits						

3.3.1 Rice cultivation and production

The plains in the Vientiane province accounts for the major rice producing plain in Laos. The rainfed agricultural system is the most popular in rice production although supplementary irrigation is available in some areas. With the increase in demand for crops in Vientiane, this basin represents an agricultural system in transition from traditional to commercially oriented (Shivakoti, et al., 2014).

In terms of regional, the Vientiane province has significant contribution to the increase in national rice production. Since the mid-1990s, the overall production has been increased in these regions due to the mainly expansion of the rice fields and secondly improvement in yields. The other reason for increased yield is also due to the 65% adoption rate for the improved varieties in the wet season and 100% in the dry season (Eliste & Nuno, 2012).

The rice is cultivated for one rotation in slash and burn land type while it is cultivated for four rotations in paddy fields. In the lowland valleys, average rice yield is higher compared to the hills. Rice is the main crop as it is cultivated in 5800 ha of total land in NXRB as shown in Table 5. Upland rice cultivation is very low compared to lowland due to narrow valley floors. The rice is produced very less in the dry season which is 5% of production in the wet season. (DWR, 2009).

Table 5. Total harvested area used and rice yield in Nam Xong river basin

Year	Rainfed			Irrigated			Total	
	Area (ha)	Yield (T/ha)	Production (T)	Harvest Area(ha)	Yield (T/ha)	Production (T)	Area (ha)	Production (T)
1995-1996	3550	3.5	12425	80	3.95	316	3630	12741
1998-1999	3872	3.7	14326.4	420	4.2	1764	4292	16090.4
1999-2000	4195	3.95	16570.25	0	0	0	4195	16570.25
2000-2001	4150	3.8	15770	0	0	0	4150	15770
2001-2002	4149	3.85	15973.65	324	4.25	1377	4473	17350.65
2002-2003	4187	3.97	16622.39	0	0	0	4187	16622.39
2003-2004	4187	3.78	15826.86	367	4.25	1559.75	4554	17386.61
2004-2005	4381	3.8	16647.8	0	0	0	4381	16647.8
2005-2006	4750	4.16	19760	300	4.7	1410	5050	21170
2006-2007	4860	4.16	20217.6	250	4.7	1175	5110	21392.6
2007-2008	5000	4.2	21000	344	4.8	1651.2	5344	22651.2
2008-2009	5200	4.39	22828	262.5	4.87	1278.375	5462.5	24106.375
2009-2010	5500	4.5	24750	300	5	1500	5800	26250

Sources: Department of Agriculture, Vangvieng District, (2014)

The area for rice production has been increased but the yield has been almost doubled. There is no good information on use of fertilizer. Very less farmers use fertilizer for rice cultivation because It is believed that the soil fertility is good enough. The yield had decreased for few years which was due to lack of water supply and irregular climate (Miaillier, 2007).

3.3.2 Crop Calendar

The rice is grown in most of the area in the wet season. The wet season upland rice on average is longer cultivation season compared to the lowland. In the lowlands, rice planting typically starts from the first of June and is harvested from mid-October while planting starts in upland around mid-April and is harvested from mid-September. The typical duration for the rice cultivation in lowland from planting to harvesting is 4 to 5 months as shown in Figure 9.

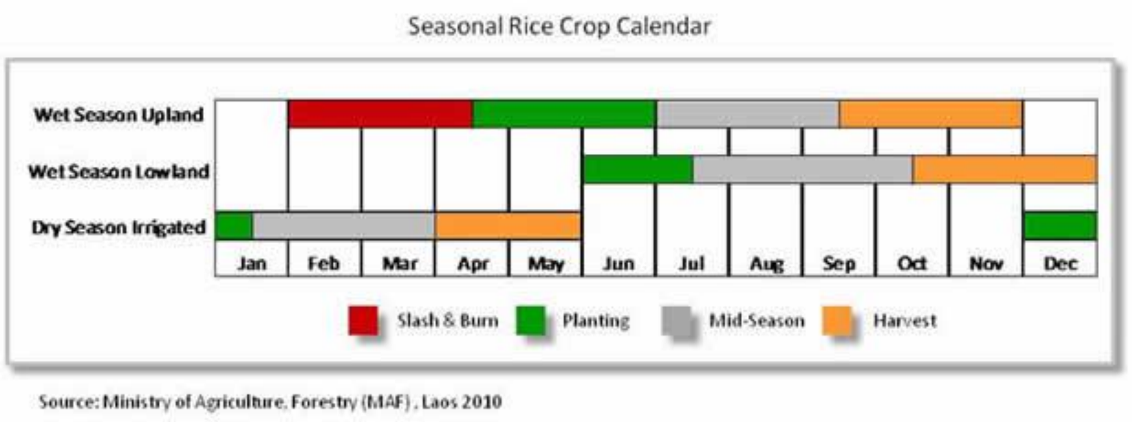

Figure 9. Seasonal rice crop calendar in Lao PDR (USDA, 2011)

3.3.3 Irrigation

The NXRB utilizes two types of rice cultivation: upland or rainfed rice and the irrigated rice. The rainfed rice cultivation is practiced in highland which does not require diversion from water way but irrigated rice needs diversion. Yearly, approximately, 189,522,600 m^3 of water is used for irrigation in the basin (DWR, 2009). The irrigation water required daily in NXRB in given in Table 6.

Table 6. Current daily irrigation water requirement in Nam Xong river basin (Sayasane, 2013).

Irrigation unit (10,000m3)	Daily irrigation water requirement											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Lower Nam Xong	0.51	0.13	0.13	0.06	0.01	0	0.58	0	0	0.03	0.01	0
Middle Nam Xong	9.59	2.54	2.43	1.2	0.12	0	24.17	0	0	1.46	0.46	0
Total	**10.09**	**2.67**	**2.55**	**1.27**	**0.13**	**0**	**24.75**	**0**	**0**	**1.49**	**0.48**	**0**

The research is only limited to rainfed agriculture and irrigation is not considered in this thesis. But all rice in the model is assumed rainfed to evaluate the impact of climate change.

4 Data and Research Methodology

The overall framework of the research process is as shown in Figure 10 below. The framework consisted of the theory, study of the area, rice yield projection, discussion and conclusion.

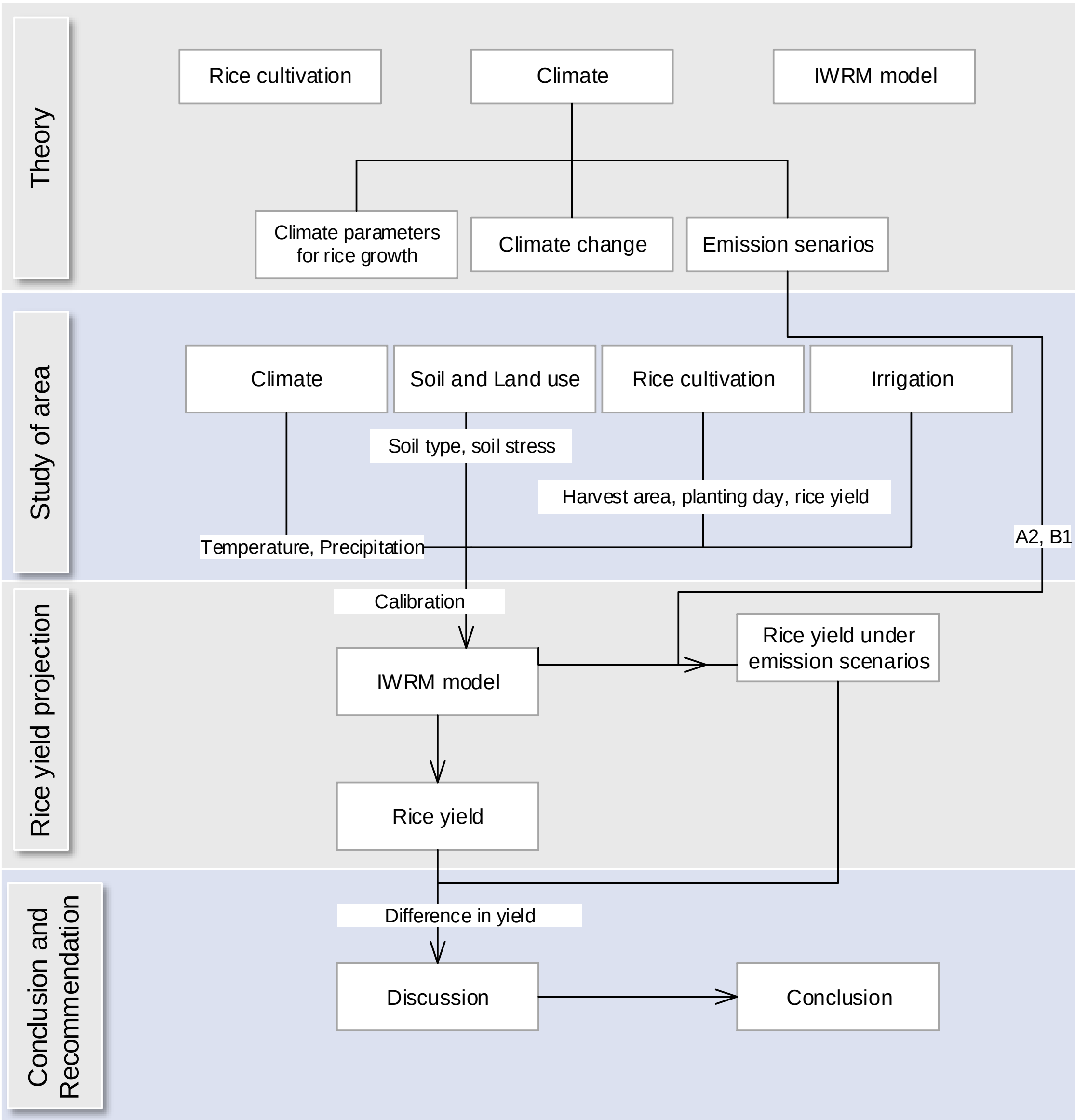

Figure 10. Overall research methodology

The Nam Xong river basin consists of varying geography ranging from mountains, valleys to flat plains. The idea of this research is to study the geography, climate and land use of river basin to simulate the rice yield and compare the output with the climate change scenarios. Initially, the theory behind the rice growth and its primary contributor parameters were studied, followed by the state of the climate and soil condition and, existing tradition of the rice cultivation in the river basin. It is to be noted that, despite the state of climate and soil condition, the tradition of rice cultivation has high impact on yield (FAO, 2000).

After studying theoretical background behind rice growth and farming and, thorough research on the study area, calibration has been made in three different time series points of upland, lowland valley, and flat plains. According to calibration results, model follows the trend well but the observations are limited to compare, due to only ten measurements from the year 2001 to 2009. Since, the purpose of the model is to predict the rice yield from input information, there can be uncertainties in predicted results, however, these results can be used to make a decisive conclusion. In this study, rice yields are being forecasted for each year and optimized to observed statistical data. With same calibration the model is then simulated under climate change scenarios and forecasting from the simulation are used for analysis and making conclusions.

The main approach of the research is to study the impact of climate change on rice yield. However, predicting future for rice yield under climate change scenarios is beyond the scope of this project. Consequently, the approach is to simulate the model under these scenarios within the same year as used for comparing results to observed data. The results from baseline scenario and climate change scenario are described and analysed in this study as the researcher can have confidence that difference in yield from these two different conditions can have a similar trend in future.

4.1 Limitation of the Study

The common limitation throughout the study is due to the gaps in information and lack of quality data. In the case of this study, there is no proper data of irrigated agriculture. Ironically, there is no prior information of the rainfed rice yields on a specific area (upland, lowland). There is no data which can specify which area have significant yield. It was the problem during simulating the yield, as model calculates yield for grid cell which represents 250*250 m area. The yield is roughly analyzed with information that; higher rainfall area has the higher yield than lower rainfall areas.

There is no specific information on crop calendar as it cannot be specific in all the agricultural areas and can be different in different years. The deviation of crop calendar can be week depending on the climate. Therefore, crop calendar is roughly estimated and the harvesting day is also roughly estimated.

Another limitation of the study is the input in model in nutrient level. The nutrient level has a high impact on agriculture. In the model, it is indicated by soil stress, but soil stress has wide definition such as water holding capacity, drainage, depth, texture, organic matter and fertility of the soil. Therefore, no prior information on these issues is described in model. The model also gives slightly more yield, therefore, harvesting day was chosen wisely to match the observed data.

4.2 Data description and Input Data requirement

The IWRM model requires daily values of weather data of precipitation and temperature, crop data such as planting day, water stress, soil stress and conductivity and irrigation values.

4.2.1 Climate data

The climate data includes daily temperature and precipitation of the area. Precipitation data in the model is collected from Hin Heup, Vangvieng and Kasy weather stations while temperature data is only collected from Vangvieng station.

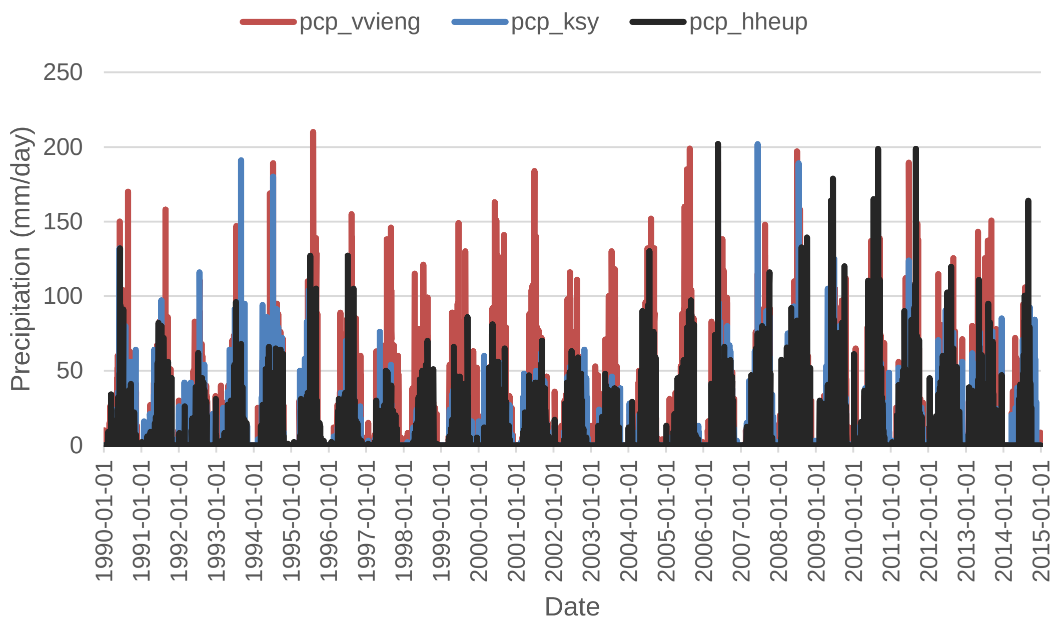

Figure 11. Precipitation data from Vangvieng, Kasy and Hin Heup weather station (1990-2014). Data acquired from model

The precipitation is not uniform in all the areas as shown in Figure 11. Vangvieng receives more rainfall annually than other two stations. Vangvieng is located in a valley which is the main reason for receiving higher rainfall. It is also the key reason for most of the rainfed rice cultivation in the Vangvieng. Hin Heup weather station is located in the lowlands, therefore, it receives less rainfall than other areas Whereas Kasy receives medium rainfall and is located in upland areas.

As in the previous discussion, it was concluded that the amount of rainfall has a direct impact on the agriculture and the rice yield, therefore, rice yield for all the areas are not uniform in NXRB. Due to high rainfall and good soil condition for agriculture, valleys around Vangvieng have more rice cultivation area than in lowland and upland areas and therefore more rice yield than other areas. Due to low rainfall in Hin Heup, it has less rice yield than other areas. Other than Vangvieng, most of the agricultural land is irrigated agriculture.

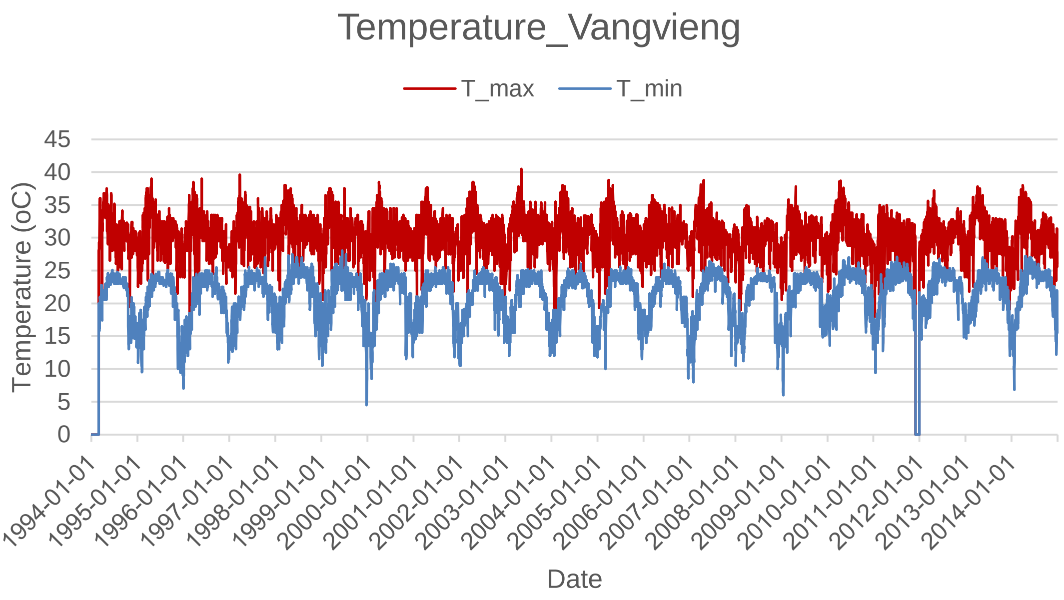

Figure 12. Maximum and minimum temperature data from Vangvieng weather station. Data acquired from model

4.2.2 Global Circulation Models Scenarios (GCMs)

The GCMs models are the numerical models which simulate the increasing GHG gases from the response of global climate system. It represents the physical process in atmosphere, ocean, cryosphere and land surface. Six different GCMs which are selected from total 18 models on the basis of their performance in the simulation of precipitation. But only four out of those six models are used in model where GCM temperatures values were downscaled to NXRB by using statistical downscaling. The GCMs and scenarios that best fits the model are given in Table 7.

Table 7. Global Circulation Models used in model (NREI, 2015).

GCM	Scenario	Time frame	Spatial resolution
CCCMA_CGCM3.1	B1 A1b A2	1850-2300 1850-2300 1850-2100	48 rows x 96 columns 3.75° x 3.75°
CNRM_CM3	B1 A1b A2	1860-2299 1860-2299 1860-2099	64 rows x 128 columns ~2.8° x 2.8°
NCAR_CCSM3	B1 A1b A2	1870-2199 1870-2099 1870-2099	128 rows x 256 columns ~1.4° x 1.4°
MIROC3.2Hires	B1 A1b	1900-2100 1900-2100	160 rows x 320 columns ~1.1° x 1.1°
GISS_AOM	B1 A1b	1850-2100 1850-2100	60 rows x 90 columns 3° x 4°
MPI_ECHAM5	B1 A1b A2	1860-2200 1860-2200 1860-2100	96 rows x 192 columns ~1.9° x 1.9°

4.2.3 Crop parameters

The purpose of crop parameters is to describe the crop characteristic in terms of soil, water use, and climate which were already calibrated in the model as default values. By studying the NXRB, the parameters are to be calibrated to simulate the model and to get the output yield as close to the observed data. By selecting the crop, crop parameters were applied.

Different crops have different value of crop parameters. In this study, fallow was applied in the model and the paddy rice was chosen as aqua crop type. The upper and lower water depth was set for wet rice in North and Central Lao PDR. The Julian calendar was used for managing planting day. The parameters are shown in Table 8.

Table 8. Input data of crop parameters used in IWRM model

Parameters Description	Value of rainfed	Units
Average AquaCrop maximum temperature	32	ºC
Average AquaCrop minimum temperature	22	ºC
Planting day	152	-
Irrigation coefficient	1	-
Yield coefficient	0.7	-
AquaCrop water stress	Full stress	-
Aqua soil stress	0.3	-
Potential evapotranspiration correction coefficient (pet-corr)	0.8	-
Vertical conductivity for the infiltration model (infkz)	0.1	-
Vertical conductivity of the soil layer 1 (kz1)	0.05	-
Vertical conductivity of the soil layer 2 (kz2)	0.1	-

In the model, the petcorr affects the evaporation. Infkz affects how fast water infiltrates through the surface layer to soil layer 1 which is important for dry season base flow. It is also important during high precipitation events because slow infiltration means the storage is filled up faster leading to overland flow. Kz1 affects how fast water infiltrates through the soil layer 1 to soil layer 2. Kz2 is similar to kz1, except affects vertical conductivity inside soil layer 2. This is also another variable that is important for dry season base flow.

5 Results

A calibration process was done by applying historical climate data, soil and crop parameters on the baseline period to the model. After the simulation of the model from a calibration process, the output yield from the model from the year 2001 to 2010 was compared with the observed yield in the same years and a statistical analysis was carried out to find the precision of the model. Primarily, a trial method was applied to find the accepted output yield with the observed yield.

5.1 Calibration of crop parameters

In the model, the development of specific crops is evaluated by planting days followed by temperature, water and soil stress, conductivity of soil layers, irrigation and evapotranspiration. The calibration of those values is provided in Table 8.

The harvesting day is roughly estimated from the growth duration of rice plants as shown in Figure 1. For the vegetative phase of the rice plant, the medium duration of 55 to 75 days, 35 days for the reproductive phase and 30 days for the ripening phase were taken into account. On other hand, harvesting day of 120 to 140 days from the planting day were taken into account. The simulated yield is given in Table 9.

Table 9. Observed and simulated yield for rainfed rice in NXRB

year	Observed		Simulated			
	harvest Area(ha)	Yield (T/ha)	Yield (T/ha)	Planting day	Harvesting day	Growth duration
2000-2001	4150	3.8	3.801	152	277	125
2001-2002	4149	3.85	3.86	152	276	124
2002-2003	4187	3.97	3.97	152	278	126
2003-2004	4187	3.78	3.838	152	275	123
2004-2005	4381	3.8	3.795	152	275	123
2005-2006	4750	4.16	4.137	152	280	128
2006-2007	4860	4.16	4.186	152	280	128
2007-2008	5000	4.2	4.201	152	281	129
2008-2009	5200	4.39	4.38	152	282	130
2009-2010	5500	4.5	4.496	152	290	138

The model calibration is a quite lengthy and laborious task. Due to the lack of proper data, a hit and trial method was applied. Different values of soil stress and planting day were taken into account during the calibration step. The first measured rice yield was compared with the computed yield. The match was evaluated subjectively.

5.2 Model evaluation

The harvesting day considered during the research was 120-140 days. Therefore, an average value of the yield from 120-140 days from the planting day was calculated. Then the average simulated rice yield was compared with the observed rice yield to assess the goodness of the model. A paired two sample t-test was performed to compare the means of the observed and simulated yield. The result of the model performance is given in Table 10.

Table 10. Results from paired two sample t-test

Statistic parameters	Observed yield	Simulated yield
Average Yield (tons/ha)	4.06	4.13
Standard deviation	0.259	0.125
t stat	-1.202	
p-value	0.259	

The null hypothesis for the t-test is, true difference in means of the observed and simulate yield is equal to zero. According to the p-value, a null hypothesis is not rejected, which concludes that, there is no significant difference in the means value of the observed yield and simulated yield. As shown in Figure 13, the observed and simulated yield are not equal and uniform. As discussed before, the simulated yield are the average yields of 120 to 140 harvesting days in the model.

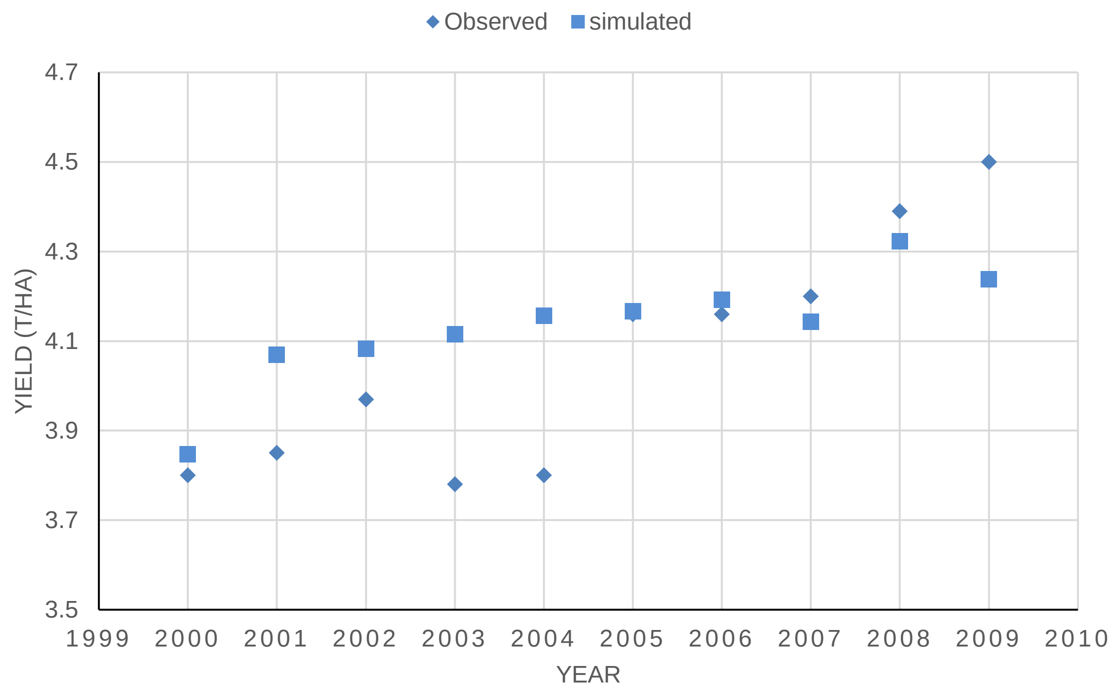

Figure 13. Observed and Simulated yield for rainfed rice.

5.3 Yield projection under climate change

Yield under climate change is achieved by simulating the model using climate projection as input. Only precipitation and temperature is assumed to change in future. Only projection scenario for precipitation is taken as input in weather stations due to the limitation and error from the model. The primary idea is to calibrate and simulate the model to get yield value close to the observed yield and use the same calibration to obtain yield under different scenarios and compare the results. The calibration of model is provided in Table 8.

The GCMs used in model were CCCMA_CGCM3.1, CNRM_CM3, NCAR_CCSM3 and MPI_ECHAM5 and, A2 and B1 scenarios were chosen from those models. These scenarios were downscaled by statistical scaling using three different time series of precipitation: historical time series, baseline and projection. The model was simulated for each year from 2000 to 2009 using baseline and both scenarios A2 and B1 for four different GCMs model individually. This sums up 10 runs for baseline and 20 runs for both scenarios of four GCMs which was total of 90 simulation of models. The simulated yield was then converted to ESRI ASCII file and then imported to R studio for further analysis.

Evaluation of rice yield under climate change scenarios can only be done after the evaluation of yield under baseline. So it is vital to understand the yield map under baseline before making any conclusions for climate change induced results. The yield map from baseline is shown in Figure 14. Ironically, the map shows more yield than observed. It is because, the map shows highest possible yield for each year. If a certain day is fixed as a planting day in the model, it calculates the rice yield for all possible harvesting days.

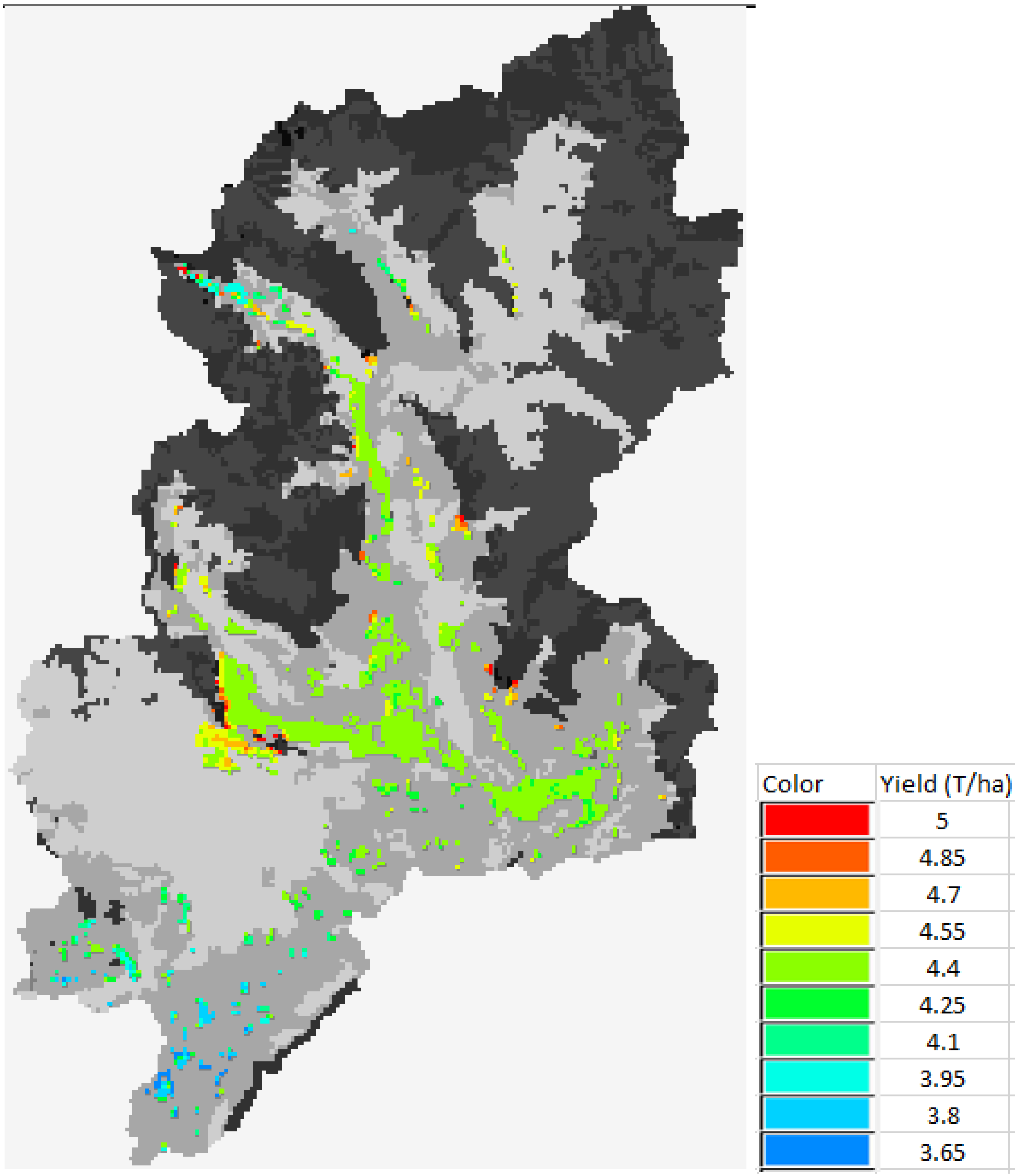

Figure 14. Average yield (tonnes/ha) using baseline from 2000 to 20009

The most of the area covering green colour in the map represents the rainfed agriculture whereas other colours indicate the irrigated agriculture area. According to Department of Water Resources, Lao PDR, approximately 5800 hectares of land was used for rice cultivation in the year 2010 but the land area used by the model is 7900 hectares. It is due to the model resolution in which landuse of a highest area is chosen.

Vangvieng is located in mountain valley as shown in Figure 7. The maximum area having green colour in yield map in Figure 14 represents Vangvieng. Due to the geographic location, it receives higher rainfall and consequently has moderately high yield than other areas in the map. The lower part of the map is covered by Hinhurp district and is located in the lowland. Due to this geographical condition, it receives subsequently less rainfall than other areas. It is not suitable for rainfed rice agriculture. Hence, most of the area used for rice cultivation is irrigated. But, due to lack of quality data, Hinhurp was not calibrated using irrigation parameters. Consequently, the model only simulates rice yield using only meteorological data. Therefore, the map shows less yield for those areas, as it receives less rainfall. High yield from range 4.7 tons/ha is due to high elevation and high rainfall in Kasy. Therefore, high yield in the areas of the model is due to rice suitable geographical conditions which receive sufficient rainfall during growth season.

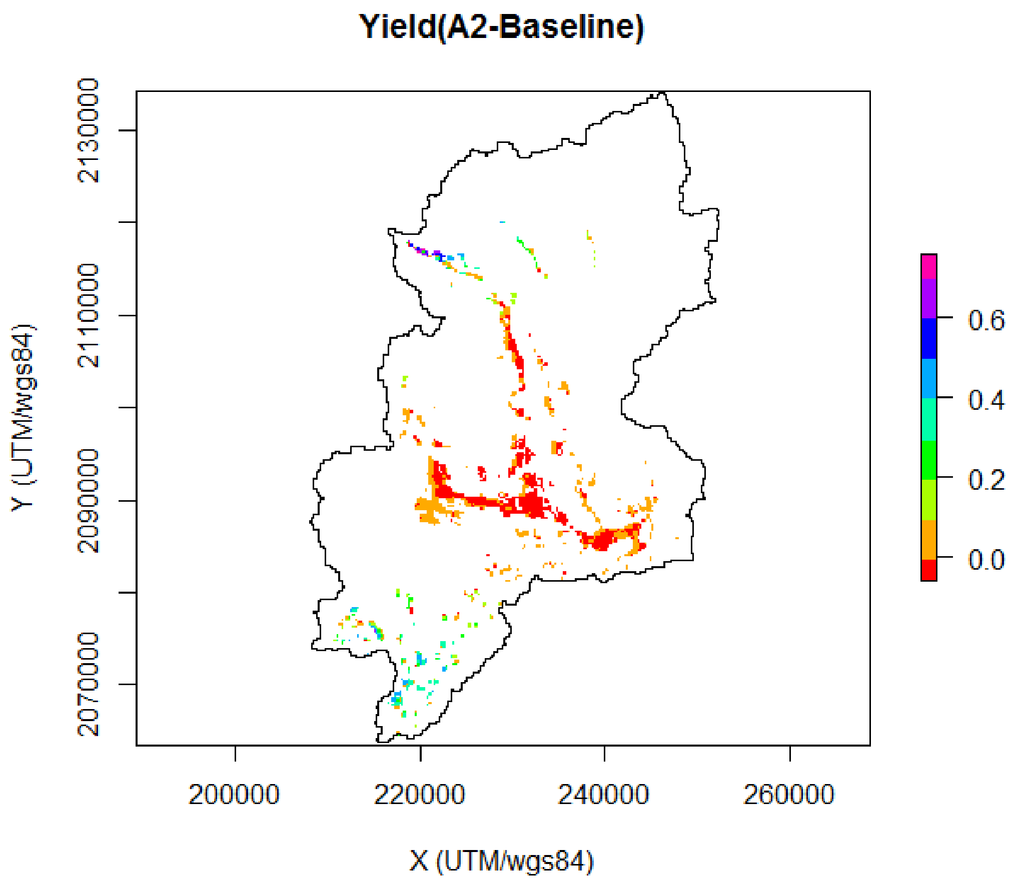

Figure 15. Difference in yield (tonnes/ha) between A2 Scenario and Baseline

Yield under A2 scenario is the average of each A2 scenario of all GCMs. The map in Figure 15 can be interpreted as rainfed rice agriculture encounters yield loss whereas irrigated areas responses yield gain under those climatic conditions. The red colour in the map indicates the loss in yield whereas other colours indicate the yield gain. The yield gain in the map represents most of the irrigated agriculture. Unfortunately, due to lack of proper information and data of irrigated agriculture, there was no simulation of the model under irrigation condition. But the model itself calculates the yield in those areas under rainfed condition. The rainfall pattern in Vangvieng as shown in below can be used to analyse the rice yield.

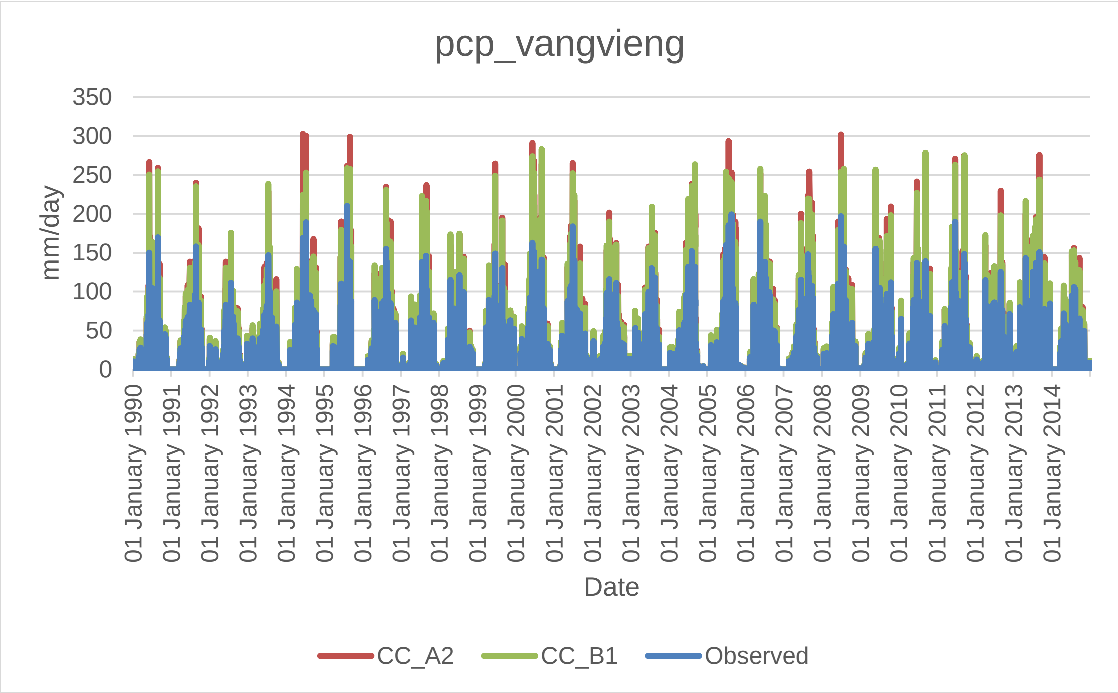

Figure 16. Observed precipitation data from Vangvieng and scaled A2 and B1 scenarios. Data acquired from model

Above figure shows the historical or observed precipitation from year the 1990 to 2014. It also shows the scaled temperatures for A2 and B1 scenarios for CCCMA_CGCM3.1 model. The trend under A2 shows the highest increase in precipitation nearly twice as observed whereas, B1 precipitation trend shows the one and half time higher than observed.

There was a lack of information on irrigation on rainfed areas, we assume that rice yields in those areas are directly affected by the amount of rainfall received. Due to climate induced precipitation change, Vangvieng areas receives excess rainfall than baseline but upland in Kasy and lowland Hinhurp receive moderate rainfall. In a case of A2 scenario, there is a maximum loss of 0.061 T/ha in rainfed areas as it receives excessive rainfall than baseline. While upland areas in Kasy receive moderate rainfall among other areas due to climate change and faces maximum gain in yield of 0.76 T/ha.

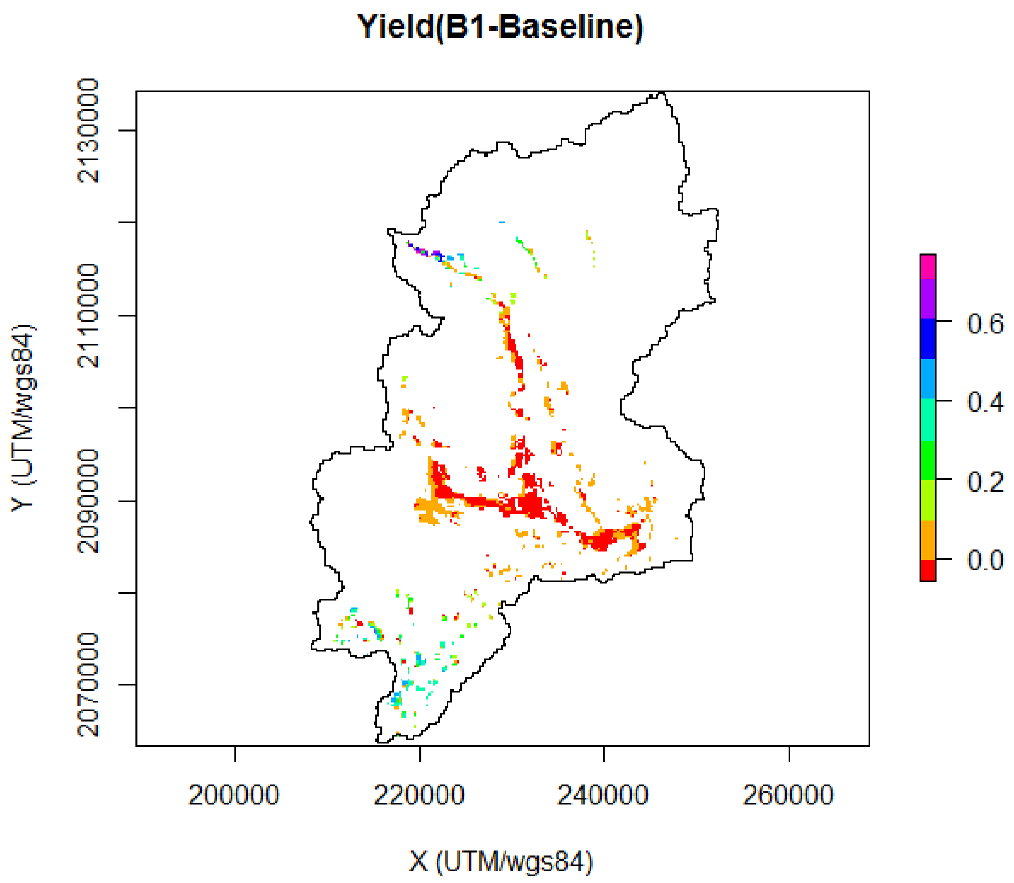

Figure 17. Difference in yield (tonnes/ha) between B1 Scenario and Baseline

Under B1 scenario, rainfed agriculture encounters maximum loss of 0.058 T/ha while upland areas in Kasy faces maximum gain in yield of 0.77 T/ha. The yield difference map due to B1 scenario is provided in Figure 17.

5.3.1 Overall impact from climate change

There is no significant difference in yield under A2 and B1 scenario. But there is slightly more yield under B1 scenario than in A2 scenario. The loss is also slightly less under B1 scenario. The highest increase and highest decrease in yield can be seen in Table 11.

Table 11. Overall difference in yield (T/ha) under A2 and B1 scenarios. Data acquired from R output.

Difference	Diff_A2	Diff_B1
Increase	0.759	0.768
Decrease	-0.0614	-0.0583

In the model, 71% agricultural land is used for rainfed rice cultivation and encounters less yield due to the climate induced rainfall change. But remaining 29% is used for irrigated rice cultivation and receives more rainfall than baseline under climate change scenarios. The increasing trend of rice yield in irrigated areas cannot be explained by this research as there was no input information of irrigation provided in the model. On the contrary, it can be interpreted as these areas benefits from climate change induced precipitation if they rely on precipitation instead of irrigation.

The observed rainfall pattern and climate change scaled precipitation data for Vangvieng can be seen in Figure 16. With scaled precipitation data, it can be observed that, under climate change scenarios, Vangvieng will receive excessive rainfall during the wet season. As already discussed in the theory section, excessive rainfall can have negative impact on agriculture and particularly rice. For simulation of climate change induced yield, no other factors than precipitation were taken into account. As a consequence of excessive rainfall, the rainfed area in Vangvieng can be considered to suffer water logging potential rice production reduction.

6 Discussion

One of the major economic and agricultural activities in the Nam Xong basin is represented by rice production. The southern region of Vangvieng with rolling hills and valleys accounts for the largest rainfed rice cultivation area in NXRB. The agricultural profile and data are integrated to Vmod software and results were analysed in a R studio which were useful in order to investigate the impact of climate change on rice yield.

Rice plants among other plants require huge volume of water for growth and development for both the reproductive and the vegetative phase. Therefore, rice production especially in rainfed conditions is highly dependent on precipitation. But, temperature also plays a leading role in plant growth and development which is unfortunately is not taken into account in this research. There were limitations and errors while downscaling the temperature data. So, this research is completely based on the climate induced precipitation change.

The projection of climate in the study area shows that the precipitation is expected to increase in the future. The southern region of Vangvieng, i.e., the central valley areas in the basin, receives already high and enough rainfall for rice cultivation. The impact of precipitation change due to climate change in these areas is problematic and excessive rainfall is expected to decrease the rice yield in future. Rice yields are expected to decrease by more than one percent than the baseline.

The landuse for irrigated rice cultivation accounts for a one-fourth of the agricultural land. Irrigated rice cultivation is mostly done in low plain lands in the NXRB which receives limited rainfall. For research purpose, irrigation data was not reliable and proper for NXRB. So, it is excluded from the research. But those areas are also expected to have increased precipitation. The rice yield in these areas is benefited by increased precipitation because as discussed earlier these areas receive less rainfall which is not enough for good rice yields. From the results, the rice yield is expected to increase in future in irrigated areas, if considered they only depend on rainfall during wet seasons.

7 Conclusion

The study assessed the potential effect of climate change regarding the precipitation change in the Nam Xong river basin with IWRM model. The basin was concluded to have increased precipitation due to A2 and B1 climate change scenarios.

The rice production environment within NXRB has an enormous climate diversity. In the main lowland valley rice growing areas in the central region in NXRB, there is a risk of loss of rice yield. The climate induced precipitation change was found to result in approximately a 1.5% loss in rice yields. The analysis was limited to precipitation change only. However, the research on the impact of climate change on rice yield need to be supported by a further analysis. The analysis should be incorporated with factors such as precipitation change, land use change and soil related information. With high probability of occurring excessive rainfall, farmers should be aware of plant diseases and pests, which can also result in lower crop yields.

The information and data concerning nutrients and calendar concerning planting and harvesting is unclear and difficult to maintain. The crop calendar was kept constant for all the ten years but in reality, it can deviate from one week to two weeks. The calibration of the IWRM model had to be based on specific soil related parameters. The observed rice yield data was available for only ten years (2000-2009) which is also not enough to validate the model.

The analysis is brief and limited, and no clear interpretations and suggestions can be made for the socio-economic mitigation. According to yield maps for a rainfed area, longer duration between planting and harvesting day seemed to be more productive than shorter or medium duration.

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Observed and Scaled precipitation data of A2 and B1 scenarios

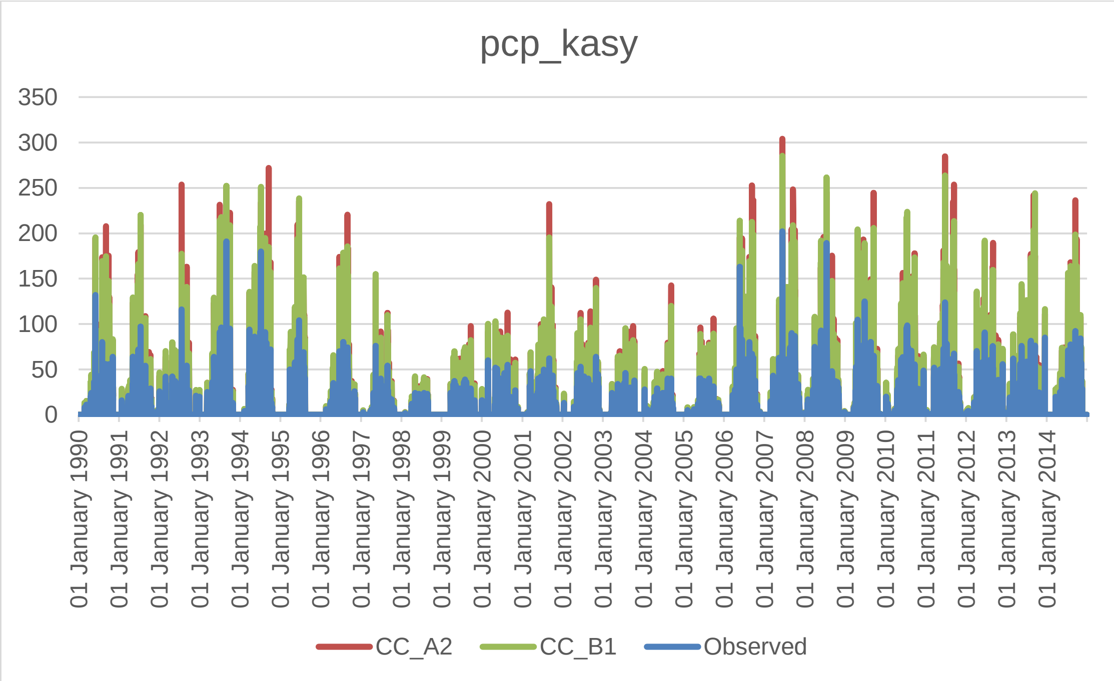

Figure 18 Observed precipitation data from Kasy and scaled A2 and B1 scenarios.

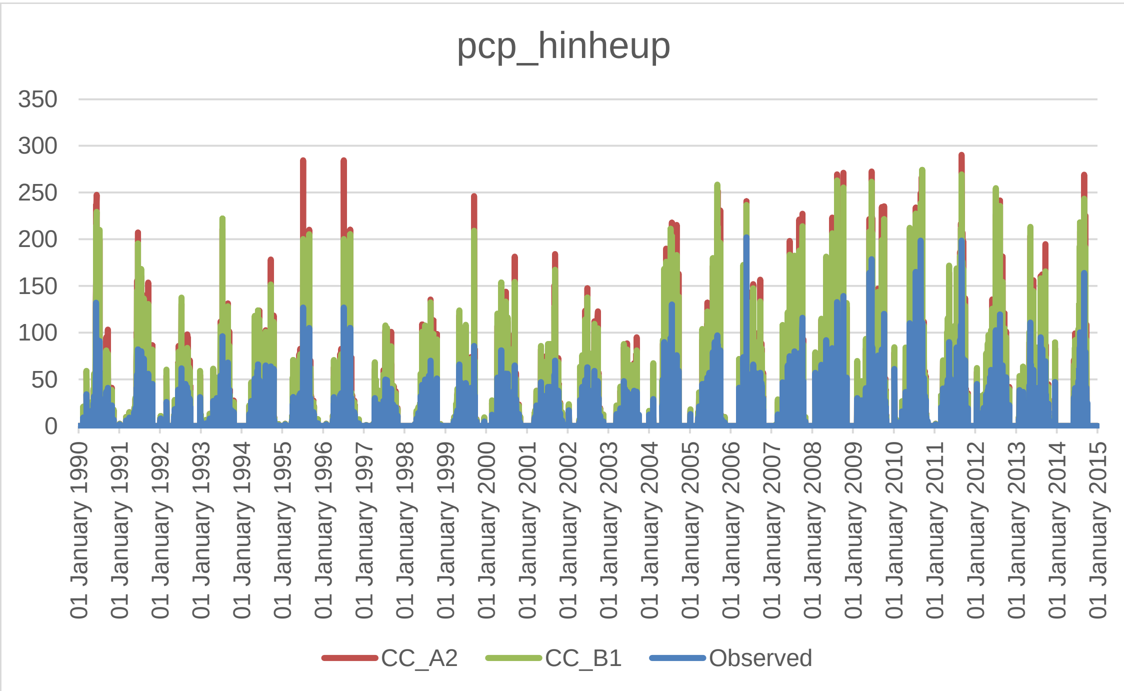

Figure 19. Observed precipitation data from Hin Heup and scaled A2 and B1 scenarios.

Introduction to the Nam Xong IWRM model

The Nam Xong model is gridded and distributed model developed by Environmental Impact Research Centre of Finland (EIA). The model has a grid cell resolution of 250m. The main input information for the model are climate and geographical data and other inputs are based on calibration. The model is capable of computing hydrology, water quality, flooding and sedimentation and, simulation crop yield, irrigation, erosion, etc.

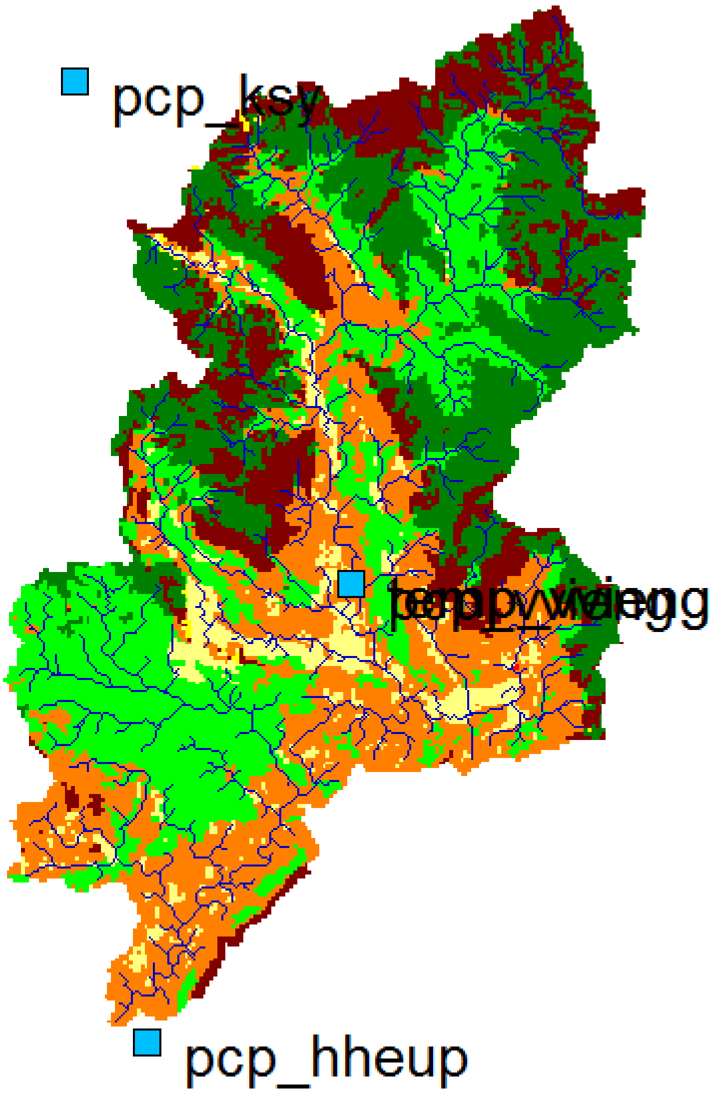

Figure 20. Land use map of the Nam Xong River Basin and weather stations incorporated to the model.

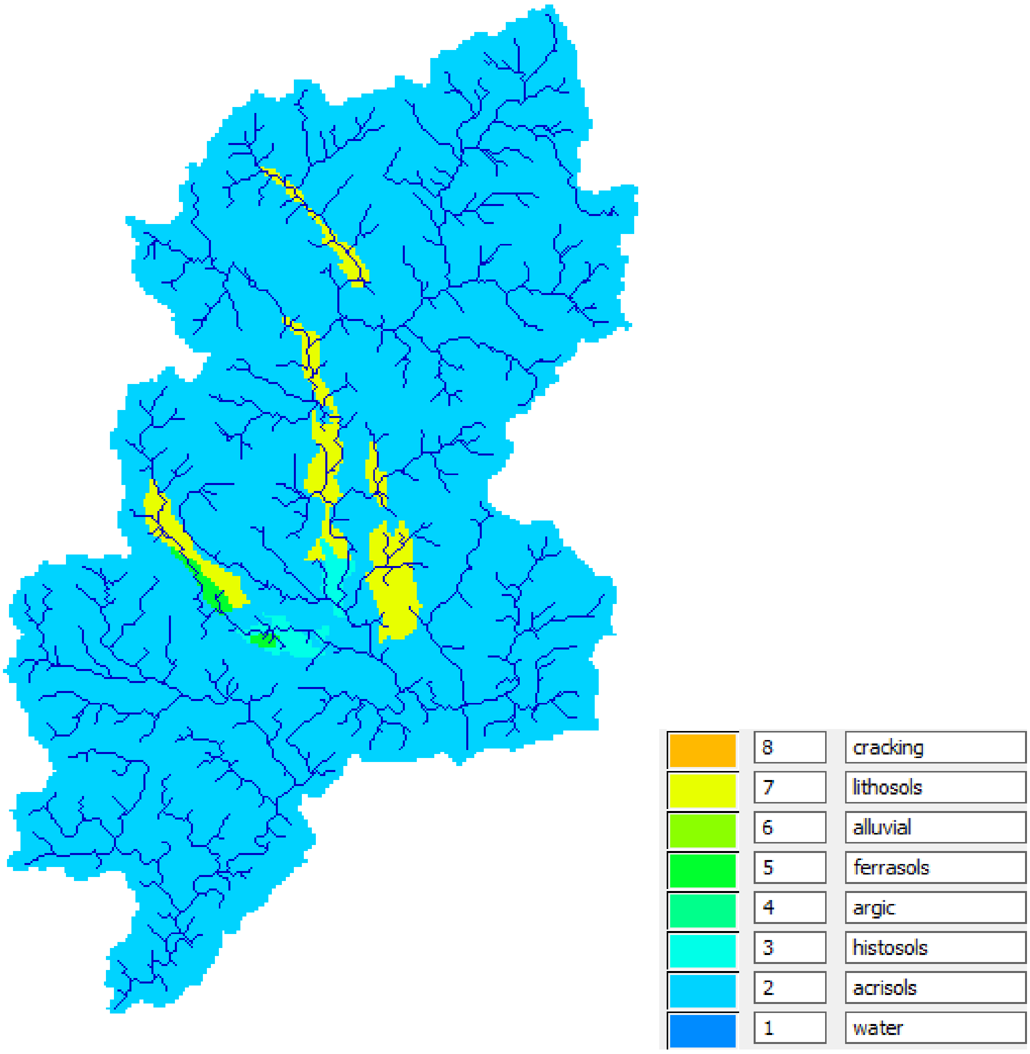

Figure 21. Soil classification from Nam Xong model.

From map, it can be seen that, most of the area is covered by acrisols followed by lithosols, where most of rice is cultivated.

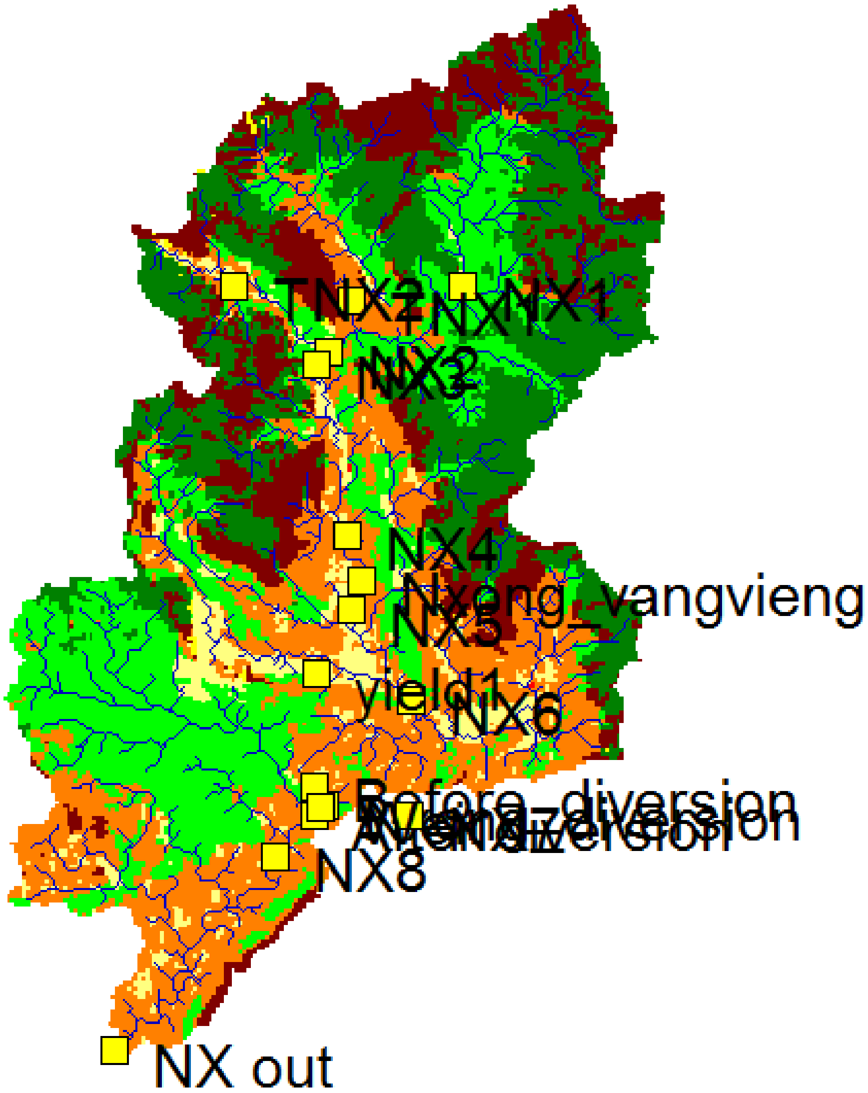

Figure 22. Time series points of the Nam Xong model.

In the model, agricultural area has been assigned a time series point to monitor the rice yield for each year. These time series points also can be used to monitor meteorological data, sediments, erosion, irrigation demand, etc.